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IDENTIFICATION OF THE VIBRATIONAL ERROR OF THE ACCELEROMETER THROUGH THE BENCH TESTS

Introduction. One of the most requirements for accelerometers is vibration stability. It is characterized by the ability of an accelerometer to provide the correct information about measured acceleration with a certain accuracy during vibration.

The criterion of vibration stability in the case of an accelerometer is named vibratory error, which is characterized as a change of the constant component of the output signal. It is difficult to calculate and compensate for the vibrational errors of an object, because it is highly dependent on the vibration profile experienced by the accelerometer, and it can vary from one application to the other.

All currently available methods for identifying vibrational errors are based on dynamic accelerometer tests (mainly on the vibration stand), which allow us to investigate its work in conditions close to the real ones. However, such tests require expensive equipment and have numerous factors which deteriorate the accuracy of the estimation. Therefore, our task is to develop such method, which requires only static tests.

Objectives. To develop the static method of determining the additional constant component of the output signal of the navigational accelerometer under the action of deterministic and random vibrations on it.

Methods. The output signal of the accelerometer (fig. 1) can be expressed as a function of the input acceleration as follows:

$$U = K_1 \left\{ \begin{array}{l} k_0 + \left(1 + \dfrac{k_1'}{2}\operatorname{sign} a_{\mathrm{IA}}\right) \cdot a_{\mathrm{IA}} + \sum\limits_{n \ge 2} k_n a_{\mathrm{IA}}^n + \delta_{\mathrm{OA}} a_{\mathrm{PA}} + \delta_{\mathrm{PA}} a_{\mathrm{OA}} + \\ + k_{\mathrm{IP}} a_{\mathrm{IA}} a_{\mathrm{PA}} + k_{\mathrm{IO}} a_{\mathrm{IA}} a_{\mathrm{OA}} + k_{\mathrm{PO}} a_{\mathrm{PA}} a_{\mathrm{OA}} + k_{\mathrm{PP}} a_{\mathrm{PA}}^2 + k_{\mathrm{OO}} a_{\mathrm{OA}}^2 + \dot{\varepsilon} \end{array} \right\} \quad (1)$$

where K_1 – accelerometer sensitivity; k_0 – offset; k_1' – asymmetry of sensitivity; δ_{OA}, δ_{PA} –non-orthogonality of the accelerometer instrumental axes; k_n $(n \ge 2)$ – n-th order coefficient of nonlinearity; k_{IP}, k_{IO}, k_{PO} – cross-sensitivity; ε – measurement noise. Consider the case of a simple sinusoidal input acceleration

$$\begin{bmatrix} a_{\mathrm{PA}}^* & a_{\mathrm{IA}}^* & a_{\mathrm{OA}}^* \end{bmatrix}^{\mathrm{T}} = \begin{bmatrix} a_{\mathrm{PA}} & a_{\mathrm{IA}} & a_{\mathrm{OA}} \end{bmatrix}^{\mathrm{T}} + \begin{bmatrix} w_{\mathrm{PA}} & w_{\mathrm{IA}} & w_{\mathrm{OA}} \end{bmatrix}^{\mathrm{T}} \sin \omega t \quad (2)$$

where $a_{\mathrm{PA}}, a_{\mathrm{IA}}, a_{\mathrm{OA}}$ –acceleration projections; $w_{\mathrm{PA}}, w_{\mathrm{IA}}, w_{\mathrm{OA}}$ –vibration projections; $\omega = 2\pi f$ – vibration frequency. The time-averaged value of this input is zero. The time-averaged output is equal to the sum of the time-averaged values of all components on the right side of the equation (1). The odd order terms average out to zero:

$$e = \frac{k_2}{2} w_{\mathrm{IA}}^2 + \frac{3}{2} k_3 w_{\mathrm{IA}}^2 a_{\mathrm{IA}} + 3k_4 a_{\mathrm{IA}}^2 w_{\mathrm{IA}}^2 + \frac{3}{8} k_4 w_{\mathrm{IA}}^4 + \frac{k_{\mathrm{IO}}}{2} w_{\mathrm{IA}} w_{\mathrm{OA}} + \frac{k_{\mathrm{IP}}}{2} w_{\mathrm{IA}} w_{\mathrm{PA}} +$$
$$+ \frac{k_{\mathrm{PO}}}{2} w_{\mathrm{PA}} w_{\mathrm{OA}} + \begin{cases} 0, \text{when} \left| a_{\mathrm{IA}} \right| \geq \left| w_{\mathrm{IA}} \right|; \\ \dfrac{k_1'}{\pi} \left[\arcsin \dfrac{a_{\mathrm{IA}}}{w_{\mathrm{IA}}} + \sqrt{w_{\mathrm{IA}}^2 - a_{\mathrm{IA}}^2} - \dfrac{\pi \left| a_{\mathrm{IA}} \right|}{2} \right], \text{when} \left| a_{\mathrm{IA}} \right| < \left| w_{\mathrm{IA}} \right|. \end{cases} \quad (3)$$

The obtained model of vibration error is the function of asymmetry, even nonlinearity and cross-sensitivity. These coefficients are subject to experimental determination during the tests according to the next method.

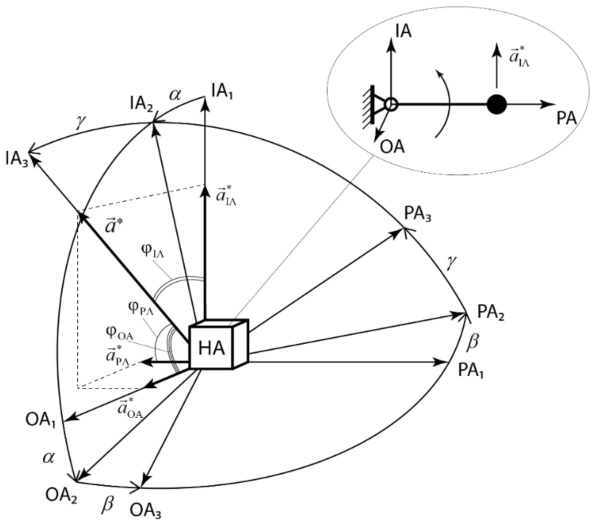

Fig. 1. Orientation of the acceleration vector relative to the accelerometer instrumental axes

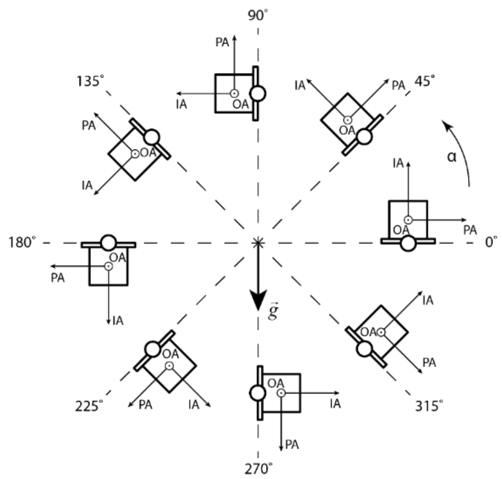

Fig.2. Test positions of NA

The test positions of accelerometer are divided into three series, depending on which axle accelerometer is parallel to the axis of rotation (Fig. 2). We measure accelerometer's output signal U_{ij} in these positions and find coefficients of the model (1) using next equations:

$$k_3 = \frac{\sqrt{2}}{\tilde{K}_1} \left(U_{16} - U_{12} - \frac{\sqrt{2}}{2} \left(U_{17} - U_{13} \right) \right) - 2;\ k_0 = \frac{1}{12 \cdot K_1} \left(\sum_{i=1}^{2} U_{i3} + \sum_{i=1}^{2} U_{i7} + \sum_{i=1}^{8} U_{3i} \right);$$

$$k_4 = \frac{1}{K_1} \left[U_{11} + U_{15} - \left(U_{12} + U_{14} + U_{16} + U_{18} \right) \right] + 2k_0 + \left(2\sqrt{2} - 1 \right) \tilde{k}_1';$$

$$k_{\mathrm{IP}} = \frac{1}{2K_1} \left(U_{12} + U_{16} - \left(U_{14} + U_{18} \right) \right);\ k_{\mathrm{IO}} = \frac{1}{2K_1} \left(U_{22} + U_{26} - \left(U_{24} + U_{28} \right) \right);$$

$$k_{\mathrm{PO}} = \frac{1}{2K_1} \left(U_{32} + U_{36} - \left(U_{34} + U_{38} \right) \right);\ k_2 = \frac{1}{K_1} \left(\sum_{i=2}^{8} U_{1i} - \frac{U_{11} + U_{15}}{2} \right) - 3k_0 + \frac{1 - 2\sqrt{2}}{2} \tilde{k}_1'$$

$$\tilde{K}_1 \approx \frac{1}{6}\left[\left(U_{15} - U_{11}\right) + \sqrt{2}\left(U_{14} + U_{16}\right) - \sqrt{2}\left(U_{12} + U_{18}\right)\right]$$

The sources of instrumental errors in the measurement of the output signals of the NA on the static calibration stand are the systematic angular errors of the initial orientation and the random angular error of the test angles. The combined effect of these errors is expressed in the deviation of the projections acceleration on the instrumental axes of the accelerometer as follows:

$$\Delta U_i = \frac{\partial U_i}{\partial a_{\mathrm{PA}\,i}} \Delta a_{\mathrm{PA}\,i} + \frac{\partial U_i}{\partial a_{\mathrm{IA}\,i}} \Delta a_{\mathrm{IA}\,i} + \frac{\partial U_i}{\partial a_{\mathrm{OA}\,i}} \Delta a_{\mathrm{OA}\,i}$$

Results. One of the main requirements is the ability to get a large array of accelerometer's output values signal in a small time interval. It is achieved by high-speed ADC. In the experiment, the numerical values of MM's NA coefficients were determined. After that, the errors of their identification were calculated by subtraction from the founded numerical coefficients values their reference values. The dependence of the integral on the measured acceleration during the vibration action is approximately linear, which is confirmed by the fact that the vibration error of the NA for the duration of the vibration is constant in magnitude. The variable and noise components in the signal integrated over time are significantly lower than in the output signal NA, which allows us to see the effect of vibration on the accelerometer.

Conclusion. The calculations based on the developed mathematical model (3) of vibrational error coincides with experimental results, which confirms the correctness of our considerations about the form of functional dependence (3). However, we don't take into account the frequency dependence of the magnitude of the vibration. Exploring this dependency is possible only during dynamic tests.

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